CLIMATE, MORPHOMETRY AND EROSIVITY IN A HYDROFIGUREIC UNIT OF THE CERRADO OF THE FEDERAL DISTRICT: SOCIO-ENVIRONMENTAL IMPLICATIONS AND DIFFUSE RIGHTS

CLIMA, MORFOMETRIA E EROSIVIDADE EM UNIDADE HIDROGRÁFICA DO CERRADO DO DF: IMPLICAÇÕES SOCIOAMBIENTAIS E DIREITOS DIFUSOS

CLIMA, MORFOMETRÍA Y EROSIVIDAD EN UNA UNIDAD HIDROGRÁFICA DEL CERRADO DEL DISTRITO FEDERAL: IMPLICACIONES SOCIOAMBIENTALES Y DERECHOS DIFUSOS

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ABSTRACT

Global climate change tends to generate insecurity, with the increased frequency and intensity of extreme events. These effects are exacerbated by anthropogenic processes such as uncontrolled urbanization in areas strategic for water recharge and the cushioning of negative impacts, compromising the widespread right to a balanced and sustainable environment for future generations. This study conducted a climatic and hydrological analysis of a hydroFigureic unit in the Córrego Tamanduá microbasin, located in the Cerrado region of the Federal District. The approach emphasized the morphometric characterization of the basin and the effects of changes in precipitation patterns on rainfall erosivity (RUSLE R factor). Rainfall data organized into three time series (1971 to 2001, 2002 to 2012, and 2015 to 2024) were used. The effects of both total precipitation levels and precipitation concentration were evaluated. The PCI (already established) and ISC (proposed with the aid of a generative AI tool based on bootstrapping with 10,000 combinations and 95% CI) indices were used as indicators of rainfall event concentration. The results indicate changes in rainfall distribution, particularly in recent times, with increased seasonality and erosivity estimates, which intensify water vulnerability. The conclusion is that these changes pose a concrete

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threat to the collective and intergenerational right to a balanced environment, a fact exacerbated by disorderly urbanization and other anthropogenic actions that cause degradation of areas that play an important role in providing the ecosystem service of water production.

Keywords: Climate Change. Rainfall Erosivity. Ecosystem Services. Water Recharge. Diffuse Rights. Sustainable Development Goals.

RESUMO

As mudanças climáticas globais tendem a gerar insegurança, com o aumento da frequência e intensidade de eventos extremos. Esses efeitos são agravados por processos antrópicos como a urbanização desordenada em áreas estratégicas para a recarga hídrica e o amortecimento de impactos negativos, comprometendo o direito difuso ao meio ambiente equilibrado e sustentável para as gerações futuras. Este estudo realizou uma análise climática e hidrológica de uma unidade hidrográfica na microbacia do Córrego Tamanduá, situada no Cerrado do Distrito Federal. A abordagem enfatizou a caracterização morfométrica da bacia e os efeitos de alterações nos padrões de precipitação sobre a erosividade das chuvas (fator R da RUSLE). Foram utilizados dados pluviométricos organizados em três séries temporais (1971 a 2001, 2002 a 2012 e 2015 a 2024). Foram avaliados tanto o efeito dos níveis totais de precipitação quanto da concentração desta. Como indicadores de concentração dos eventos chuvosos foram utilizados os índices PCI (já consagrado) e ISC (proposto com o auxílio de ferramenta de IA generativa a partir de bootstrap com 10.000 combinações e IC 95%). Os resultados indicam mudanças na distribuição das chuvas, principalmente no período recente, com aumento da sazonalidade e da estimativa da erosividade, o que intensifica a vulnerabilidade hídrica. Conclui-se que tais alterações representam uma ameaça concreta ao direito coletivo e intergeracional ao meio ambiente equilibrado, fato esse agravado pela urbanização desordenada e outras ações antrópicas que causem degradação de áreas que cumprem importante papel no oferecimento do serviço ecossistêmico de produção de água.

Palavras-chave: Mudanças Climáticas. Erosividade da Chuva. Serviços Ecossistêmicos. Recarga Hídrica. Direitos Difusos. Objetivos de Desenvolvimento Sustentável.

RESUMEN

El cambio climático global tiende a generar inseguridad, con el aumento de la frecuencia e intensidad de eventos extremos. Estos efectos se ven agravados por procesos antropogénicos como la urbanización desordenada en zonas estratégicas para la recarga hídrica y la amortiguación de impactos negativos, comprometiendo el derecho difuso a un ambiente equilibrado y sostenible para las generaciones futuras. Este estudio realizó un análisis climático e hidrológico de una unidad hidrográfica de la microcuenca del Córrego Tamanduá, ubicada en el Cerrado del Distrito Federal. El enfoque enfatizó la caracterización morfométrica de la cuenca y los efectos de los cambios en los patrones de precipitación sobre la erosividad de la lluvia (factor R de RUSLE). Se utilizaron datos de precipitaciones organizados en tres series de tiempo (1971 a 2001, 2002 a 2012 y 2015 a 2024). Se evaluó tanto el efecto de los niveles totales de precipitación como la concentración de precipitación. Los índices PCI (ya establecido) e ISC (propuesto con la ayuda de una herramienta de IA generativa basada en bootstrap con 10.000 combinaciones e IC del 95%) se utilizaron como indicadores de la concentración de eventos de lluvia. Los resultados indican cambios en la distribución de las precipitaciones, especialmente en el período reciente, con un aumento de la estacionalidad y la erosividad estimada, lo que intensifica la vulnerabilidad hídrica. Se concluye que dichos cambios representan una amenaza concreta al derecho colectivo e intergeneracional a un ambiente equilibrado, hecho agravado por la urbanización desordenada y otras acciones antropogénicas que provocan degradación de áreas que juegan un papel importante en la provisión del servicio ecosistémico de producción de agua.

Palabras clave: Cambio Climático. Erosividad de la Lluvia. Servicios Ecosistémicos. Recarga de Agua. Derechos Difusos. Objetivos de Desarrollo Sostenible.

1 INTRODUCTION

The hydroFigurey of the Federal District (DF) is characterized by the presence of small watercourses with low flow, which are greatly influenced by climatic seasonality (Souza et al., 2012). They often occur on slopes and in embedded valleys. It is subdivided into three major hydroFigureic regions, which are Paraná; São Francisco and Tocantins/Araguaia. These large hydroFigureic regions are subdivided into seven smaller ones, which are the São Bartolomeu River Basin, the Descoberto River Basin, the Paranoá Lake Basin, the Preto River Basin, the Maranhão River Basin, the Corumbá River Basin, and the São Marcos River Basin (ADASA, 2024).

Although it registers the presence of a large number of springs, a fact associated with its strongly dissected relief and the predominant types of soils, in addition to being an important watershed at the national level, this federation unit has the third lowest water availability in the country, behind only the states of Paraíba and Pernambuco (CODEPLAN, 2020). Challenges such as large population growth, rainfall seasonality, environmental degradation, and global climate change (GCM) have imposed even more difficulties for the management of water resources in the Federal District, and it is of paramount importance not only to develop a robust legal framework and environmental planning, but also to actually implement it. Despite this, factors such as disorderly urbanization, the installation of impactful projects in unsuitable areas, as well as non-compliance with important tools such as Economic Ecological Zoning (ZEE) and Management Plans for conservation units (UCs) have been putting water resources at risk (Chelotti & Sano, 2021; ADASA, 2020).

It is important, therefore, that preserved areas or areas in different stages of regeneration, especially those present in UCs such as the National Forest of Brasília and the Environmental Protection Area of the Central Plateau (APA Planalto Central) have their Management Plans prepared, implemented and respected as a strategy for the conservation of water resources. More specifically, the Planalto Central APA was created by the Decree of January 10, 2002, occupying an area equivalent to 70% of the Federal District and has a very well-structured Management Plan (ICMBIO, 2015), but often not taken into account when occupying and using the land.

The Tamanduá Farm, headquarters of Embrapa Vegetables, is completely located in the Planalto Central APA and has some areas of Cerrado in different stages of regeneration. Part of the area constitutes a hydroFigureic unit located in the microbasin of the Tamanduá Stream, being one of the few strongholds conserved or in regeneration of the microbasin, also presenting a good number of springs and water quality, being registered in the Rural Environmental Registry (CAR) of Embrapa Vegetables, an instrument imposed by Law

12.651/2012, as a remnant of native vegetation and, along the watercourses and springs, as Permanent Preservation Areas (APPs). This area, which was the object of the present work, in spite of the fact that it fulfills important ecosystem services for the maintenance of Embrapa Vegetables' research activities and, consequently, for farmers throughout the country, and also for the various small and medium-sized rural producers present in the region, has been suffering strong pressures due to the accelerated urbanization process.

The pedogeomorphological characterization of the area was carried out by Lima et al. (2025). The authors verified that the landscape is composed of Plateaus, Borda de Chapada, Intermediate Plateaus and Embedded Valleys. Red-Yellow and Red Latosols predominate, followed by Haplic Cambisols. Less developed soils such as Litholic Neosols, Plinthosols and Fluvic Neosols can occur occasionally. These pedogeomorphological aspects make the area an important repository of surface water resources, buffering negative impacts on them and, in the case of the Borda de Chapada, mainly, very susceptible to erosion and, consequently, to siltation of water bodies in case of removal of vegetation.

The erosivity of rainfall, a factor originally proposed by Wischmeier & Smith (1978) for the universal soil loss equation (USLE), which is a function of the quantity and intensity of this phenomenon, has been determined in several studies at the national (Lima et al., 2023) and regional (Galdino, 2015) levels. The first authors classified the erosivity of rainfall in Brazil as high compared to other regions of the planet. Galdino (2015) also found high rainfall erosivity in a regional cut for the state of Goiás (GO) and the Federal District, however, registering lower values than those found by Lima et al. (2023). In the regional cut, Galdino (2015) found an average erosivity value for the DF of 8,024 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$. In the context of global climate change (GCM), the occurrence of extreme rainfall and drought events is projected to increase (IPCC, 2023). In fact, climate data observed in long sequences, as well as those projected using different models, for different Brazilian regions, have pointed to an increase in the frequency and intensity of extreme rainfall events, with the possibility of even greater increases in the future with GCMs (Ballarin et al., 2023; Costa et al., 2025). This intensification of extreme events has a potential effect on erosivity (Almagro et al., 2017), increasing the intensity of erosive processes (Barbosa et al., 2024), making it even more important to maintain environmental balance in areas with a relevant role in water recharge.

It is necessary to remember that article 225 of the Federal Constitution of Brazil states that: "*Everyone has the right to an ecologically balanced environment, a good for the common use of the people and essential to a healthy quality of life, imposing on the Government and the community the duty to defend and preserve it for present and future generations*". Among the instruments found by the legislator to ensure compliance with this article is the establishment of Conservation Units (UC), defined by Law 9.985/2000, which "*Regulates article 225, § 1, items I, II, III and VII of the Federal Constitution, establishes the National System of Nature Conservation Units and provides other provisions*". The Environmental Protection Areas (APA) are one of the instruments for this, having their management plans as crucial tools to regulate the use and occupation of the soil, as well as environmental conservation. Other instruments such as the National Environmental Policy (PNMA), the National Water Resources Policy (PNRH), the National Climate Change Policy (PNMC) and the Forest Code (FC), as well as existing jurisprudence, impose on public authorities and the community the need to develop and apply instruments with a view to maintaining sustainability. As it represents collective and intergenerational rights, it is a clear issue related to diffuse rights (Pontes, 2019).

For all the above, the present work aimed to survey climatic and hydrological aspects of a hydroFigureic unit of the Tamanduá Stream microbasin, located in the Cerrado of the Federal District, with a view to subsidizing strategic and sustainable decision-making of land use and occupation, in compliance with the diffuse right to a balanced environment.

2 MATERIAL AND METHODS

2.1 CHARACTERIZATION OF THE STUDY AREA

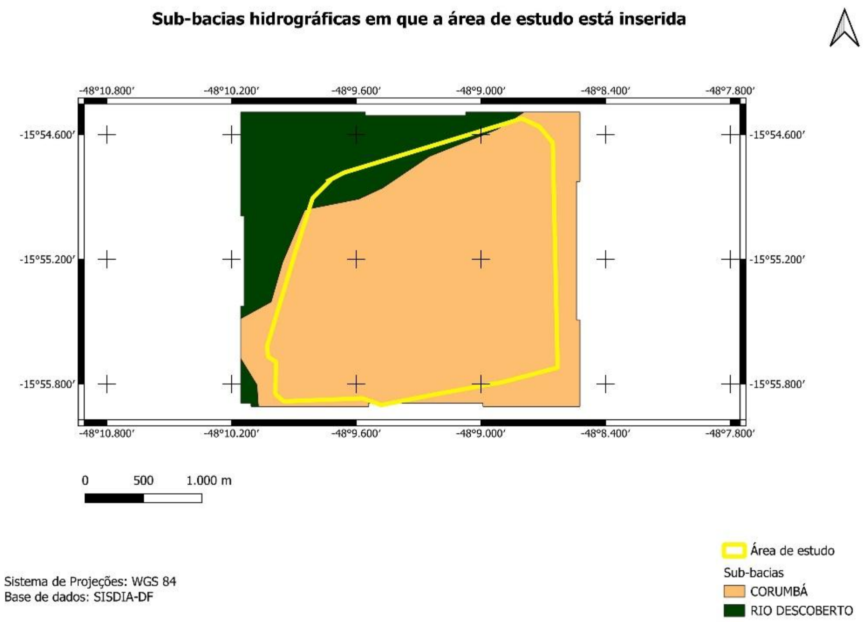
The study area (Figure 1) is located in the micro-basin of the Tamanduá Stream, part of the sub-basin of the Corumbá and Descoberto Rivers (Figure 2), in a Cerrado area in the Federal District. Lima et al. (2025) elaborated their pedogeomorphological characterization. It is inserted in the Brazilian Central Plateau (PCB). In climatic terms, it is tropical savannah (Aw) in the Köppen-Geiger classification, with very well defined dry and rainy periods. The perimeter is 8.71 km, the length is 8.67 km and the area is 4.73 km² (473 ha), being included between the following geoFigureical coordinates: To the North, 15º54'30.24''S; to the West, 48º09'51.84''W; to the South, 15º56'06''S e; to the East, 48º08'34.08''W. The altimetric amplitude was determined by Lima et al. (2025), being 124 m, with a maximum point of 1,110 m of altitude and a minimum point of 986 m.

Figure 1

3D view in the East-West direction of the study area and its delimitation (yellow polygon).

Figure 2

Insertion of the study area in the sub-basins of the Corumbá River and the Descoberto River



2.2 DATABASES USED

For the elaboration of this work, the following materials were used:

- SRTM Digital Elevation Model (MDE) with spatial resolution of 30 m x 30 m;
- Contour lines with equidistance of 5 m, obtained from the EAM;
- Google Satellite images with a spatial resolution of 0.5 m x 0.5 m;
- Map of slope classes prepared by Lima et al. (2025);
- Land use and occupation map on a scale of 1:1,000 prepared by Lima et al. (2025);

- Semi-detailed soil reconnaissance map at a scale of 1:10,000 prepared by Lima et al. (2025).

2.3 SOFTWARE USED FOR ANALYSIS

Google Earth Pro and QGIS version 3.42.3 were used for all the analyses included in this work.

2.4 CLIMATOLOGICAL DATA

All climatological data used in the present work were obtained from the Embrapa Vegetables Meteorological Station (15°56′24" S and 48°08′24" W). For the comparative analyses carried out, the following periods were used: recent period (2015 to 2024) and past periods (2002 to 2012; 1971 to 2001). The data were evaluated for the existence of trends, anomalies and measures of uncertainty (Coefficient of Variation – CV and Confidence Interval – CI). It also focused on the concentration of rainfall (PCI – Oliver, 1980) and its erosive potential. This calculates the Precipitation Concentration Index. To calculate the PCI, the following equation was used:

$$PCI = \frac{100 \cdot \sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \qquad (1)$$

Where:

Pi is the average total monthly rainfall for the period evaluated.

The following classification was then adopted regarding the concentration of rainy events (Table 1):

Table 1

Classification used for the PCI index

PCI ≤ 10	Uniform distribution throughout the year
10< PCI ≤ 15	Moderate concentration
15 < PCI ≤ 20	High concentration
PCI > 20	Very high concentration

To analyze the severity of concentrated rainfall, an index called (Concentrated Severity Index) was also proposed. This index was developed with the help of Artificial Intelligence

$_i$

(Data Analyst) using PCI and specific erosivity ( ) as a basis, through bootstrap tests. Bootstrap can be understood as a statistical method of random restructuring of data with replacement to estimate the variability and empirical distribution of sample statistics, allowing inferences without relying on strict parametric assumptions (Efron, 1979). In the case in question, about 10,000 different combinations and a 95% confidence interval for the development of the SSI were analyzed, which is calculated by the following formula. $\frac{R}{P}$

$$ISC = PCI \times \frac{R}{P} \qquad (2)$$

Where:

PCI is the precipitation concentration index;

is the specific erosivity in MJ mm ha^{-1} h^{-1} per mm of rainfall. $\frac{R}{P}$

2.5 DETERMINATION OF RAINFALL EROSIVITY (RUSLE R FACTOR)

Rainfall erosivity (R factor) was calculated based on monthly average rainfall data collected by the Embrapa Vegetables meteorological station, in the Cerrado of the Federal District. Data from three periods were evaluated, namely 1971 to 2001, 2002 to 2012 and 2015 to 2024. The calculation equation used has been used in studies carried out in Brazil, including that of Galdino (2015), who evaluated this process for GO and DF.

$$EI = 68{,}730\left(\frac{p^2}{P}\right)^{0{,}841} \qquad (3)$$

Where:

EI is the monthly average of the erosion index in $MJ.mm.ha^{-1}.h^{-1}$

p is the average of the total monthly rainfall in mm

P is the average of the total annual rainfall in mm

The R factor is then calculated by adding the calculated monthly EIs, following the formula:

$$R = \sum_{i=1}^{12} EI_i \qquad (4)$$

Where:

R is the erosivity of rainfall in $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$

EI are the monthly values of the erosion index

The estimated R factor was then interpreted based on the erosivity ranges proposed by Lima et al. (2023).

2.6 DETERMINATION OF THE MORPHOMETRY OF THE HYDROLOGICAL UNIT

For the morphometric analysis of the hydroFigureic unit, the following indices were used: Form factor (Kf); Compactness Index (Kc) and Roughness Index (Ir).

The determinations of these indices were made as shown in Table 2.

Table 2

Determined morphometric indices, their formulas and basic interpretation.

Index	**Formula**	**Basic Interpretation**
Compactness (Kc)	$Kc = 0.28 \times P/\sqrt{A}$	How circular the basin is; lower value indicates higher risk of flooding
Roughness (Br)	$Go = Dd \times H$	Relief energy and erosive potential
Form Factor (Kf)	$Kf = A / L^2$	Ratio between average width and length; Risk of simultaneous flash floods

Where:

Kc = Compactness coefficient (dimensionless)

P = Perimeter of the basin (km)

A = Area of the basin (km^2)

Ir = Roughness index (dimensionless)

Dd = Drainage density (km/km^2)

H = Altimetric amplitude of the basin (km), i.e. the difference between the maximum and minimum altitude

Kf = Form factor (dimensionless)

L = axial length of basin (km) – measured along the main watercourse

These indices were interpreted together with the satellite image with high spatial resolution (0.5 m x 0.5 m) of the area.

2.7 DELIMITATION OF THE LIMITS AND AUTOMATIC EXTRACTION OF THE DRAINAGE NETWORK OF THE TAMANDUÁ CREEK WATERSHED

The delineation of the watershed boundaries, as well as the definition of its hydroFigurey, was performed automatically in a QGIS environment, using the Processing Toolbox with the GRASS complement. From this, the r.fillnulls algorithm was applied to fill in gaps caused by spurious depressions of the MDE. Then, the r.watershed algorithm was used, applied on the corrected EDM, to generate the rasters layers of flow direction and number of cells draining for each cell (accumulation indicator). The minimum size parameter of the contribution basin was adjusted to 3,000 for the entire watershed and to 1,000 for the study area (hydroFigureic unit), ensuring hydrological coherence. Subsequently, the raster layer of watershed basins, generated by the watershed, was used to automatically delimit the watershed, based on the outlet point previously identified in the field and visually checked with the aid of the DEM, contour lines and satellite image with high spatial resolution. The hydroFigurey, in turn, was extracted based on the resulting stream segments, also obtained by r.watershed, in field visits and based on the visualization of satellite images.

2.7.1 Determination of the main watercourse of the watershed

To identify the main watercourse, the r.stream.order algorithm (Strahler ordering) was applied within the GRASS environment via QGIS. The highest order channel was then determined, which was later converted to vector using r.to.vect, allowing detailed analysis of its talweg length and geometry.

2.7.2 Chemical and physicochemical analysis of water samples from the Tamanduá Stream

Samples were collected from five different samples from the Tamanduá Stream, to constitute a composite sample. These samples were analyzed in laboratories of Embrapa Vegetables for the following parameters, using their respective methodologies: pH, Dissolved Oxygen (DO) and electrical conductivity (EC) were determined using a multiparameter probe AK 88; Turbidity, concentration of nitrogenous forms, phosphate, sulfate, copper, free chlorine, total chlorine, total hardness, chromium, aluminum and total iron were determined using Exact Micro 20 multiparameter photometer and specific reagent strips. These analyses aimed to complement the previous evaluations, integrating the climatic, morphometric and water quality analyses in the hydroFigureic unit, denoting, finally, its role in providing ecosystem services and, consequently, on diffuse rights.

2.7.3 Statistical analysis and interpretation of large volumes of data

The statistical analyses, generation of Figures, as well as the interpretation of the large volume of data generated in the present work were carried out with the aid of Generative Artificial Intelligence (AI) Data Analyst. It is necessary to emphasize, however, that all processes were supervised and critically analyzed by humans and that the data used were obtained according to the processes previously described.

3 RESULTS AND DISCUSSION

The location of the hydroFigureic unit that the present study deals with is shown in the map of the watershed of the Tamanduá Stream, delineated from the MDE corrected for spurious depressions using the r.watershed algorithm of the GRASS complement in QGIS environment. Figure 3 shows its location in the watershed, while Figure 4 shows its main watercourse, showing that it is located in the evaluated hydroFigureic unit.

Figure 4

Location of the studied hydroFigureic unit (study area) in the watershed of the Tamanduá Stream

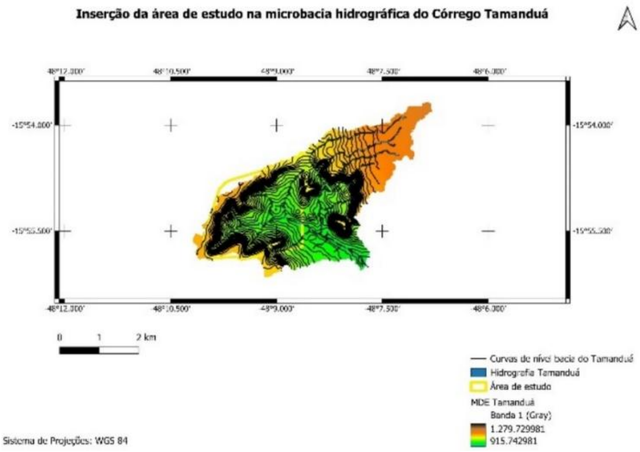
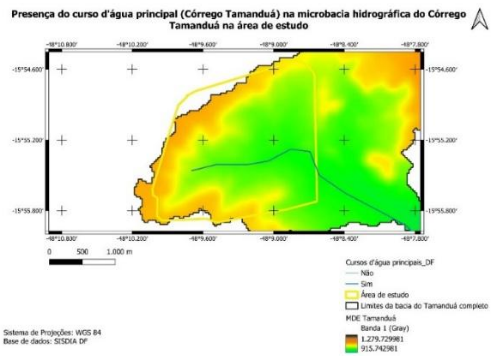


Figure 5

Main watercourse of the Tamanduá Creek watershed and its presence in the study area, including its source



It can be seen that the hydroFigureic unit is practically entirely in the microbasin, more specifically, to the southwest of it. The MDE and the contour lines point to a very common landscape in the PCB, with the presence of flat and higher areas (Plateaus) to the northeast, Borda de Chapada to the center and Intermediate Plateaus to the southwest. More specifically, the study area presents all these features, which, however, are distributed differently, with a small portion only referring to the areas of the Plateau. The MDE of the hydroFigureic unit evaluated can be found in Figure 5 and was prepared by Lima et al. (2025) from SRTM images with 30 m resolution, downloaded from INPE's Topodata database. These authors also verified the good conservation status of the area through detailed mapping of land use and occupation. It should also be noted that the area is an important repository of water resources and PPAs in a good state of conservation, as can be seen in Figure 6.

Figure 4 shows that the main watercourse, including its source, is present in the study area. This demonstrates the importance of conserving the area with a view to maintaining the quantitative and qualitative water availability of the region, where research activities maintained by Embrapa Vegetables and agricultural production by small and medium-sized rural producers are found. The maintenance of the conserved area is important to cushion negative environmental impacts, as well as to ensure the maintenance of the recharge capacity of water resources. It is worth remembering that the local climate is characterized by very well-defined rainy and dry seasons, with an important duration of the last ones, and therefore the water bodies are very dependent on water recharge, especially underground water. The Federal District has the third lowest water availability in Brazil, second only to the states of Paraíba and Pernambuco (CODEPLAN, 2020), reinforcing the need to maintain the conservation of areas responsible for the recharge of water resources.

Figure 6

Digital Elevation Model (DEM) of the study area.

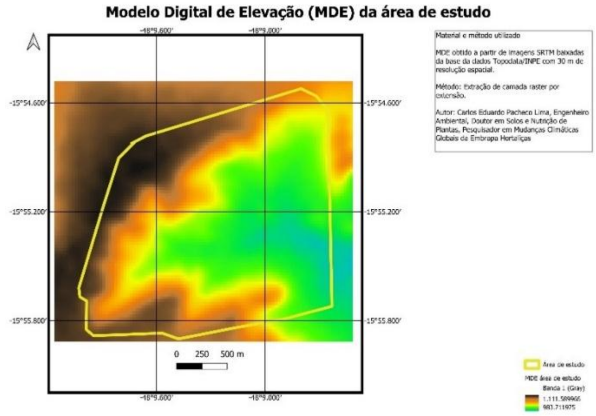
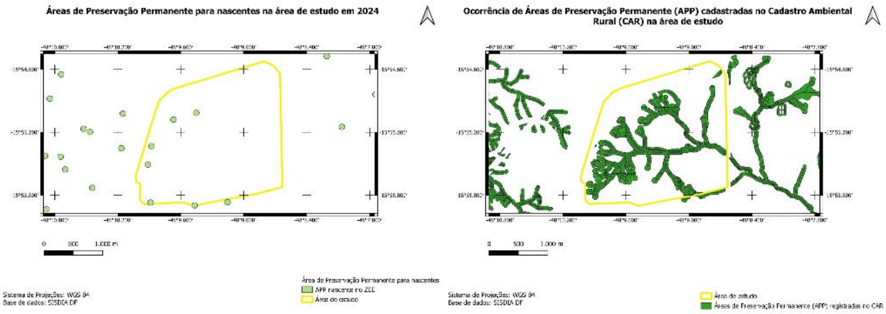


Figure 7

Occurrence of springs and APPs related to them and to the watercourses found in the hydroFigureic unit (study area).



In addition, the accelerated process of urbanization has compromised the quality of water resources, and the main river in the region (Rio Ponte Alta) is already classified as Class 3 (CONAMA Resolution 357/2005), with a strong occurrence of the silting and sedimentation process. Also, the area has a moderate impairment of the remaining T1 flow and a very high impairment of the flow that can be granted for dilution, according to information from the District Environmental Information System (SISDIA, 2023). It is important to remember that CONAMA Resolution 357/2005 establishes that vegetable crops can only be irrigated by water resources classified as Class 1 (vegetables consumed raw and/or that have direct contact with irrigation water) or Class 2 (vegetables that are not consumed raw and/or do not have direct contact with irrigation water). Table 3 shows the chemical and physicochemical characterization carried out for samples from the Tamanduá Stream. All the water quality parameters evaluated and included in the classification of water resources in CONAMA Resolution 357/2005 are compatible with Class 1, demonstrating the high quality of the water of the Tamanduá Stream and its potential use for the irrigation of vegetables. The samples were collected at the height of the dry period in the Federal District, a period when, in theory, the water would have worse quality.

Table 3

Results of chemical and physicochemical analyses of water samples collected in the Tamanduá Stream

Quality Parameter	Unit	Tamanduá Stream
ph		8,00
EC	μS/cm	10,10

OD	mg/L	6,80
Turbidity	UNT	15,00
N-NH3	mg/L	0,24
N-NO3		ND
N-NO2		ND
Total Hardness		ND
Ca2+		ND
PO43-		ND
SO42-		ND
Cu2+		ND
Free Clan		ND
Total Cl		ND
Cr		ND
Al3+		0,06
Total faith		ND

Legend: ND – Not Detected

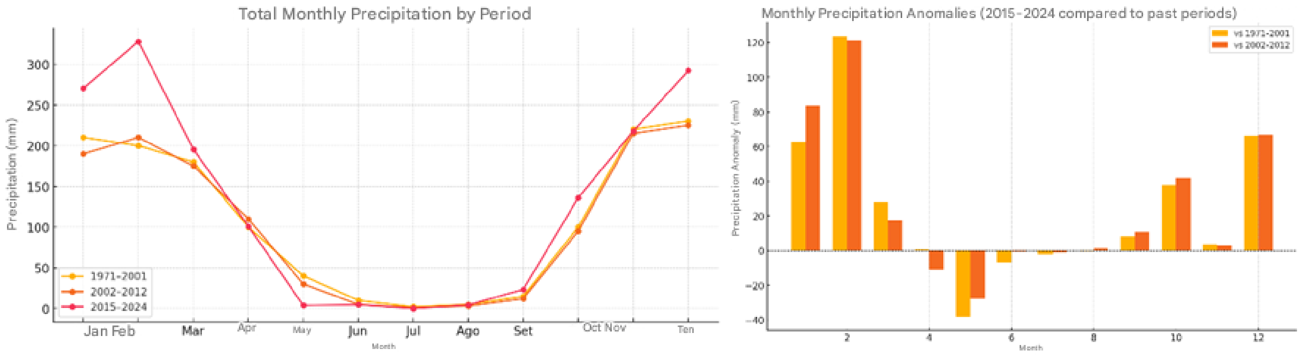
The morphometry of the hydroFigureic unit points to an almost circular shape (Kc = 1.12), very elongated (Kf = 0.06) and a slightly irregular perimeter (Ir = 228.34). The circular shape points to a moderate trend in the concentration of surface runoff, with a potential greater speed in the response to extreme precipitation events, leading to flood risks, as well as with great dependence on this process to supply surface watercourses (Braga et al., 2013). On the other hand, the slightly irregular perimeter indicated by Kf much lower than 1 denotes an elongated basin (Moro Neto, 2017), which reduces the risk of flooding mentioned above, since the runoff becomes more distributed over time. The roughness index can be classified as medium (Ir = 228.34) pointing to moderate relief energy, indicating significant erosive potential, since greater unevenness associated with higher channel density usually reflects greater sediment mobilization capacity (Fiorese & Torres, 2019). The joint analysis of these indices with the satellite image points to a hydroFigureic unit with moderate susceptibility to erosive and hydrological events, which should be taken into account when defining land use and occupation, as well as environmental planning (Trajano et al., 2012; Sehnem et al., 2015).

The area is located in a region with a predicted worsening of the water situation. Data from the Adapta Brasil platform (MCTI, 2025) point to an increase in the drought risk index on water resources and food security in the short term, reaching very high and high levels, respectively, as early as 2030, even in optimistic scenarios for GCMs. In fact, the observed data already point to a trend of worsening of the water situation, with important changes in precipitation levels, in the worsening of rainfall concentration and increase in the duration and intensity of dry periods (Ballarin et al., 2023; Costa et al., 2025). The average total annual precipitation levels between 1971 to 2001, 2002 to 2012 and 2015 to 2024 were, respectively, 1312.00 mm, 1271.00 mm and 1582.52 mm. Although there has been an increase in the levels of total annual precipitation in the last period, this was due to the concentration of rainfall in a few months, through the occurrence of extreme events, and this scenario is in accordance with that outlined in a technical note by CEMADEN (CEMADEN, 2024).

This scenario results in increased surface runoff and less capacity for water infiltration into the soil, reducing the hydraulic detention time in the hydroFigureic unit, making it more susceptible to flooding in rainy periods and reducing the flow of water bodies in dry periods. The potential for erosion (erosivity) is also increased. Figures 1 shows the comparisons between the average monthly precipitation totals and the monthly anomalies recorded for the periods evaluated.

Figure 8

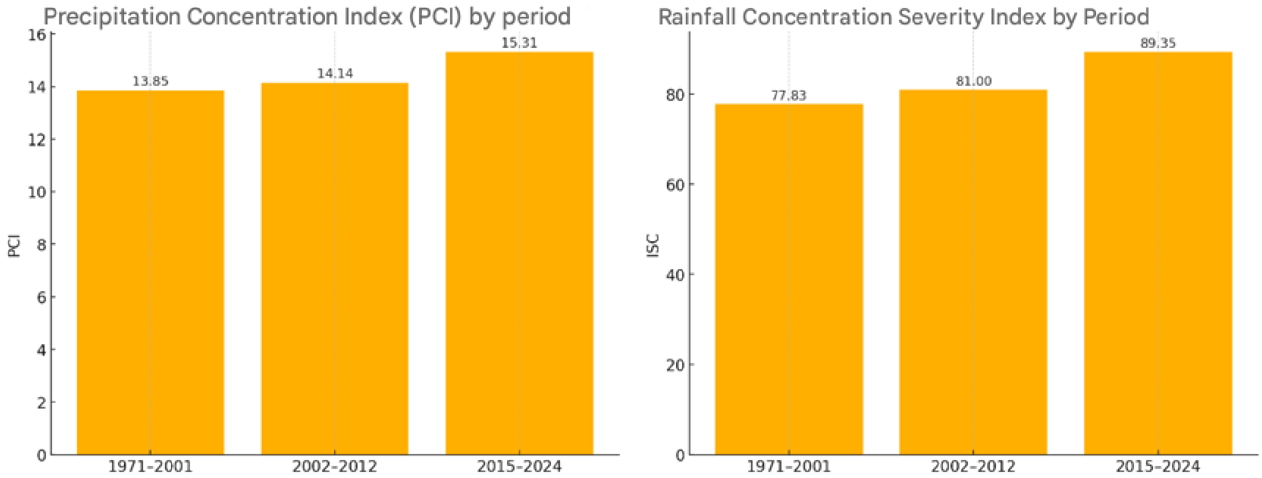
Average total monthly precipitation (left) and anomalies comparing the recent period (2015 to 2024) with two past periods (1971 to 2001 and 2002 to 2012)



The analysis of Figure 8 points to a great intensification of rainfall events in the recent period during the rainy months and an increase in the duration of the dry period by at least one month. Historically, the dry period begins in June and lasts until September. In the recent period, the period was expanded to May to September. These data support the assertion that, although an increase in total annual precipitation has been observed in the recent period, it has been at the expense of the intensification of extreme events. This phenomenon is also supported by the annual data on PCI and SSI, as can be seen in Figure 9.

Figure 9

Variation of the Precipitation Concentration Index (PCI) (left) and the Rainfall Severity Index (ISC), calculated by period for the study area. The ISC was obtained using bootstrap simulations (n = 10,000, 95%CI). Higher values of both indices indicate a higher seasonal concentration of rainfall and worsening of erosive and hydrological processes



The data shown in Figure 9 confirm the trend of increasing rainfall concentration, as well as its severity on erosive processes. Although an increase in the PCI has been observed over time, the values recorded in the periods from 1971 to 2001 and from 2002 to 2012 are very close, while that recorded in the recent period (2015 to 2024) registered a more significant increase. The ICP has been used in other studies conducted in Brazil, such as the one carried out by Nery et al. (2017), who, however, found divergent results from those found in the present study. Historically, the PCI can be classified as a moderate concentration of rainy events, while for the recent period, this index is classified as having a high concentration.

The ISC, in turn, points out that, although a reduction in the average levels of total annual precipitation was observed in 2002 to 2012 in relation to 1971 to 2001, the severity of erosivity was greater for the most recent period. The period between 2015 and 2024 presented a higher value than the first two. These results indicate a trend towards an increase in the severity of rainfall due to its concentration in short periods. These data are in line with the projections of the Intergovernmental Panel on Climate Change in its sixth report (IPCC, 2023) and other work conducted in Brazil (Lucio & Spyrides, 2016; Wanderley et al, 2018; Monteiro & Zanella, 2019; Cardoso et al, 2020). This scenario tends to worsen with GCMs, compromising the situation of water resources in Brazil, as well as their multiple uses (ANA, 2024).

There was also a reduction in the measures of uncertainty (confidence intervals – CIs and coefficients of variation – CVs) in the last period in relation to 1971 to 2001 and 2002 to 2012. The annual and monthly behavior of the data is shown in both Figure 10 and Figure 11. Such behavior may be linked to a stabilization of climatic conditions, assuming a "new normal" with the occurrence of extreme weather events. The reduction was observed for both the annual average data and most of the monthly average data for the CIs. However, the behavior is clearer for the dry period. For CVs, the values recorded for the recent period were consistently lower than those observed for the other periods, with the exception of the months of April, June and August. Although there is a hypothesis that the data point to a "new normal", the influence of other factors cannot be ruled out, such as greater precision in obtaining data for various reasons. It is necessary to draw trend lines and the observation of measures of uncertainty over longer periods and for a more robust set of data so that conclusions can be drawn. Caution in the interpretation of climate data, as well as their future projection, is preached in other studies, such as the one prepared by Ferreira et al. (2015).

Figure 10

Annual behavior of the annual (left) and monthly (right) Confidence Intervals (CIs) values for the different periods evaluated

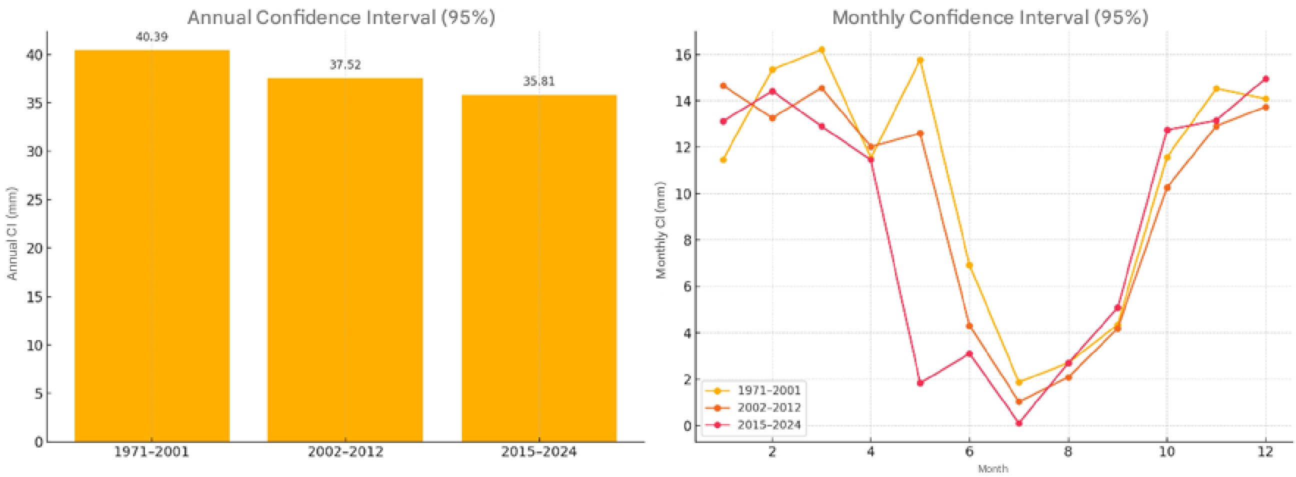
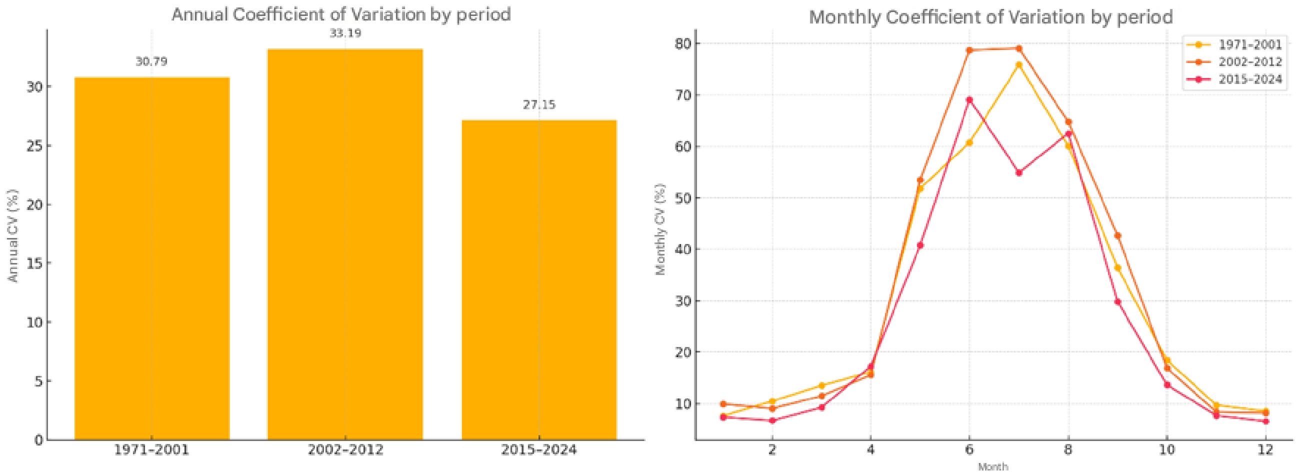


Figure 11

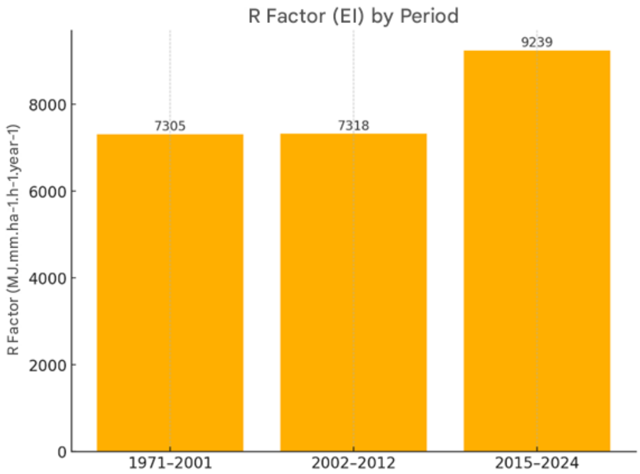
Annual behavior of the annual (left) and monthly (right) Coefficients of Variation (CVs) values for the different periods evaluated



The increase in extreme events, as well as in annual precipitation, resulted in an increase in the erosivity estimate (R factor), as shown in Figure 12. The estimates of this variable remained practically constant between the periods from 2002 to 2012 and 1971 to 2001, however, it registered an increase of approximately 1921 MJ.mm.ha-1.h-1year-1 between 2015 and 2024 in relation to 2002 to 2012. The behavior of the erosivity data Figure follows that observed for the values of total annual rainfall and for the PCI and ISC indexes, suggesting a joint action of these factors. The incidence of climate extremes can lead to changes in the hydrological cycle, putting existing water infrastructures at risk, making the population more vulnerable to extreme hydrological events such as droughts and floods, which increases water insecurity (UNESCO, 2024). A possible removal of native vegetation or vegetation currently in regeneration as a result of uncontrolled urbanization could aggravate the situation, resulting in an increase in erosive processes, which would lead to an increase in siltation and sedimentation processes (Luna Pequeno et al., 2002; Castro et al., 2013), as well as water quality, compromising ecosystem services (Costa et al., 2021).

Figure 12

Behavior of estimated erosivity (factor R of the revised universal soil loss equation - RUSLE) over the evaluated periods



R values can be classified as medium for the first two periods and high in the most recent period (Lima et al., 2023). Therefore, the observed increase was not only numerical, but also related to the potential to cause negative impacts on soil loss. Costa et al. (2025) point out that the R factor represents the erosive potential of rainfall and is influenced both by the occurrence of extreme precipitation events and by the annual total of this phenomenon.

The set of results of the work presented here reinforces the need for conservation of the study area, as reported by Lima et al. (2025). It is not only a matter of conservation and environmental preservation, but also of the right of the community to maintain its economic activities, since the area is an important source of water recharge, as well as cushioning negative impacts on regional water resources, supplying bodies of water used for research, human supply and irrigation by small and medium-sized rural producers. It is, therefore, a collective and transgenerational right, constituent characteristics of diffuse rights (Pontes, 2019). Despite the fact that the area has a robust protective framework, being located in the Sustainable Use Zone of the Planalto Central APA (ICMBIO, 2015), presenting itself as an area with biological importance and priority for the adoption of extremely high conservation actions (called São Bartolomeu River), where the adoption of good practices such as the CAR must be implemented urgently (MMA, 2005) and registered in the CAR of Embrapa Vegetables as a remnant of native vegetation with occasional occurrences of PPAs, the hydroFigureic unit has been under strong pressure due to accelerated and disorderly urbanization. This phenomenon has resulted in degradation of the cerrado and damage to water resources, as shown by Sano et al. (2010) and Chelotti & Sano (2021).

4 CONCLUSIONS AND FINAL CONSIDERATIONS

The results obtained show that the hydroFigureic unit presents itself as an important area for maintaining the quantity and quality of water resources in the region of influence. The water quality of the Tamanduá Stream points to the low level of anthropization of the area, which can be treated as an island in the face of a growing and impactful urban context. The morphometry of the basin points to erosive risks that tend to be aggravated with the increase in the occurrence of extreme weather events, as shown by the temporal evaluation of the total annual precipitation indexes, PCI and ISC. The low values of confidence intervals and coefficients of variation may indicate climate stabilization in a situation of occurrence of extremes, without, however, the influence of other factors being discarded, such as greater precision in data acquisition, and therefore it is necessary to evaluate larger temporal trends. Both the increase in total annual precipitation and the increase in the occurrence of extreme rainfall events influenced a large increase in the estimate of erosivity in the recent period (2015 to 2024). The entire scenario outlined puts at risk the capacity of the hydroFigureic unit to provide ecosystem services such as water recharge and the damping of negative environmental impacts, putting at risk the performance of economic activities such as the conduction of scientific research and the production of food by small and medium-sized rural producers, increasing the risks of socioeconomic vulnerability, water, food and nutritional insecurity. Therefore, it threatens present and future generations, constituting a threat to the fulfillment of Article 225 of the Federal Constitution, characterizing, therefore, as a threat to diffuse rights. There is also a strong alignment with the 2030 Agenda of the United Nations (UN), especially with the Sustainable Development Goals (SDGs) 6 – Drinking water and sanitation, 13 – Action against global climate change and 15 – Terrestrial life, denoting the importance and state of the art of the topic studied.

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